EuCARD²

MAX

MYRRHA Accelerator eXperiment
Research & development programme

Accelerators for ADS 20-21 March 2014 CERN

Approach for a reliable cryogenic system

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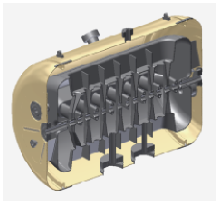
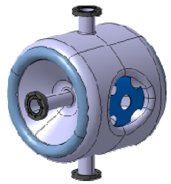
ACCELERATORS AND CRYOGENIC SYSTEMS

MYRRHA SC Linac

- SC Linac: 600 MeV - 2.5 mA proton (CW)
- ~ 100 % Superconducting RF cavities
- very high level of reliability

Sections	Injector (SC – CH)	Spoke	Elliptical
Energy	3 – 17 MeV	17 – 100 MeV	100 – 600 MeV
nb. of Cavities	12 (6 each injector)	48 (beta 0.35)	34 (beta 0.47) 60 (beta 0.65)
nb. of Cryomodules	6 (3 each injector)	24	17 (beta 0.47) 15 (beta 0.65)
			

Cryogenic operating temperature :

Proposal for the whole linac : ~ 2K

Cryogenic Heat Loads

	CH 176 MHz	Spoke 350 MHz	Elliptic 700 MHz β=0.47	Elliptic700 MHz β=0.65
Number of cavities	**12**	**48**	**34**	**60**
Static + Dynamic including couplers	**200 W @ 2K**	**680 W @ 2K**	**635 @ 2K**	**1360 @ 2K**
Total (W)	**Static (1015 W) + Dynamic (1860 W) = 2875 W @ 2K**			

MYRRHA Refrigerator capacity

Function	T (K)	Heat Load (kW)	Overcapacity	Cryo capacity (kW) @ 4.5 K
Cavities	2.1	2.875	(x 1.875) = 5.3	11.5
Couplers	5	0.5	(x 1.5) = 0.75	0.75
Thermal Shields	40	15.2	(x 1.5) = 22.8	3.5
			Total equivalent @ 4.5 K	15.75 KW

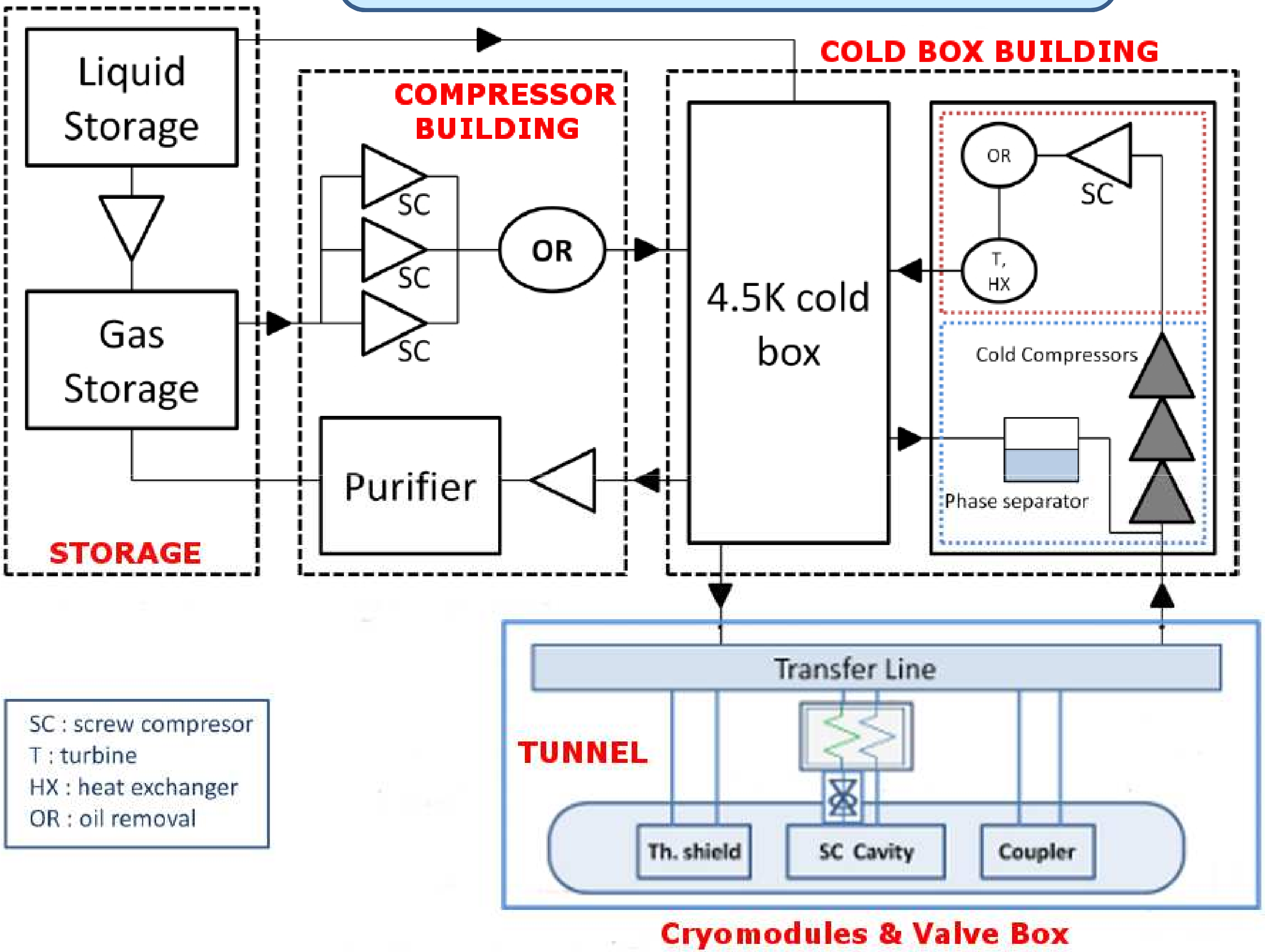
Cryogenic Plant Size similar to :
LHC (18 kW)
JLAB (11 kW)
XFEL (12 kW)

Realistic goals for the **Coefficient of Performance**

COP(2K) = 720 ; COP(4K)= 220

Total Electric (W) without overcapacity **2.3 MW**

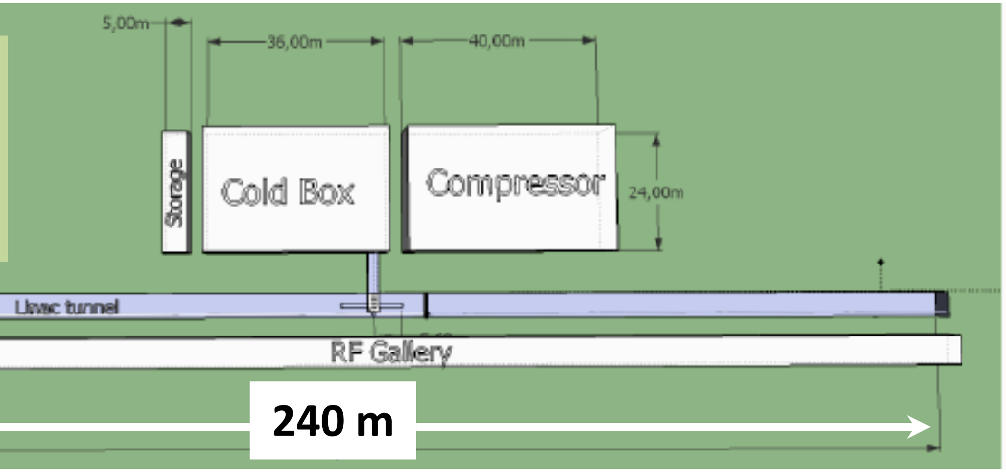
MYRRHA Cryogenic Plant Main Components

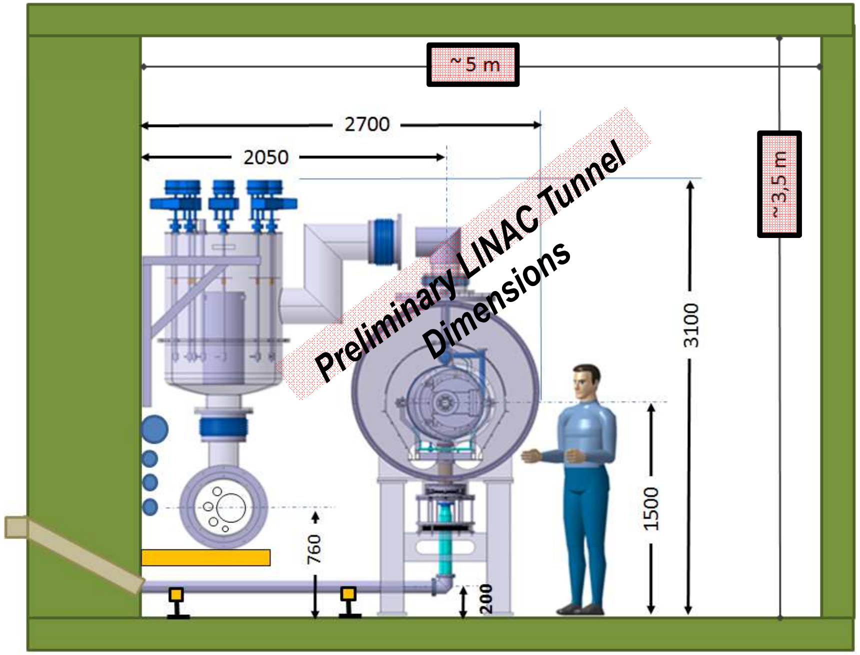


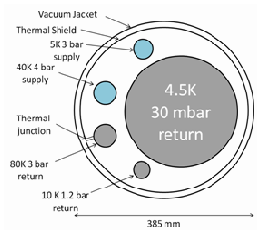
SC : screw compresor
T : turbine
HX : heat exchanger
OR : oil removal

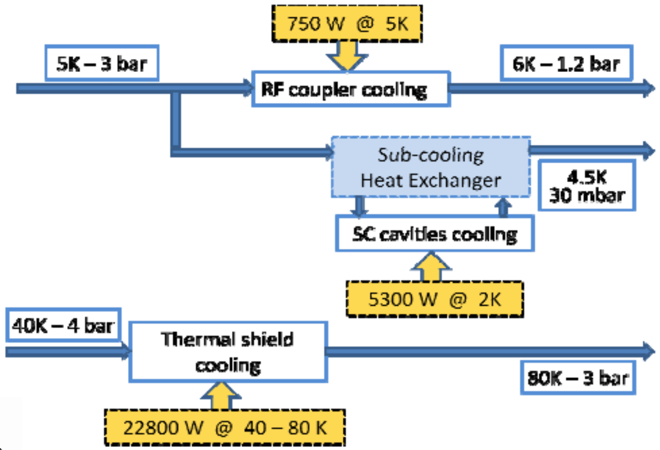
Preliminary design of MYRRHA Cryogenic buildings and Linac tunnel

- Compressor building: 40 x 24 (m²)
- Cold Boxes building: 36 x 24 (m²)
  including 4.5 K and 2K cold boxes
- Helium Liquid and Gas Storage: 5 x 20 (m²)









Cryogenic Fluids Distribution

Reliability aspects of the MYRRHA cryogenic system

Major goal for MYRRHA: to operate a 600 MeV-2.5 mA beam with less than 10 beam trips (of duration higher than 3 sec) for a 3 months period

→ equivalent to a MTBF (Mean time Between Failures) > 250 hours.

→ compared to presently running high power accelerators with MTBF of only a few hours.

Reliability improvements proposals :

1) Redundancy of the injector sections (up to 17 MeV)
2) A SC Linac operating at reasonable low accelerating gradients, to fulfill a "fault tolerance" scheme
3) Use of Solid State RF amplifiers, which can accept internal failures

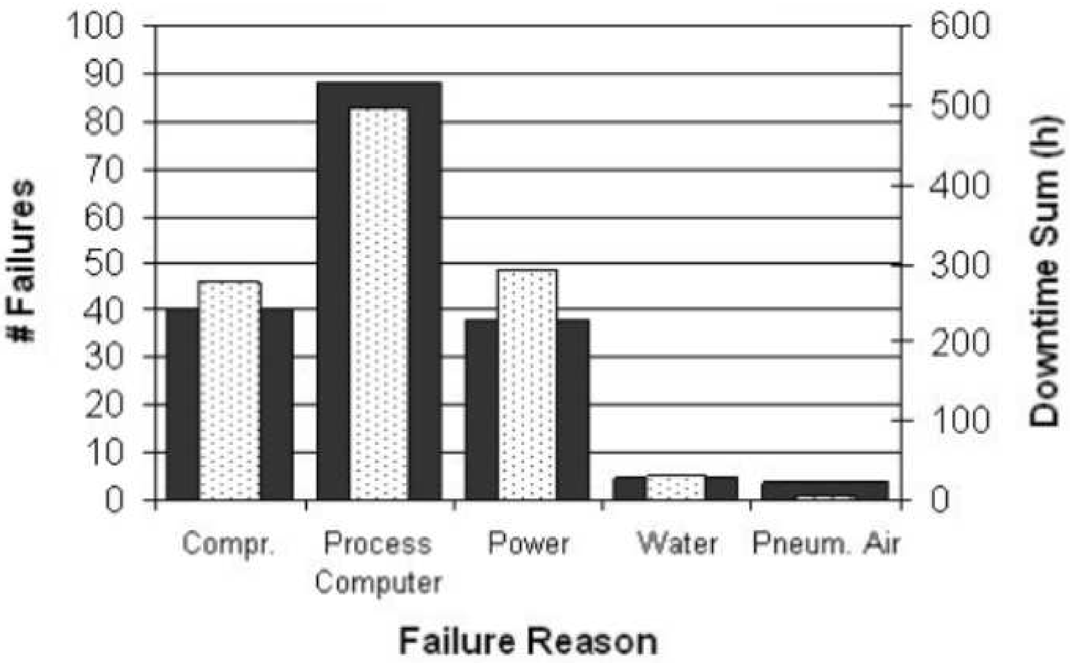
Reliability of the MYRRHA cryogenic systems:

- difficult to imagine redundancies on the main components for such a large refrigerator (perhaps only for compressors ?)
- an accident at the refrigerator level → stop the He nominal flow but can let enough time to reduce the beam power on the target and perform a safe beam stop.

Large Cryogenic Systems Reliability

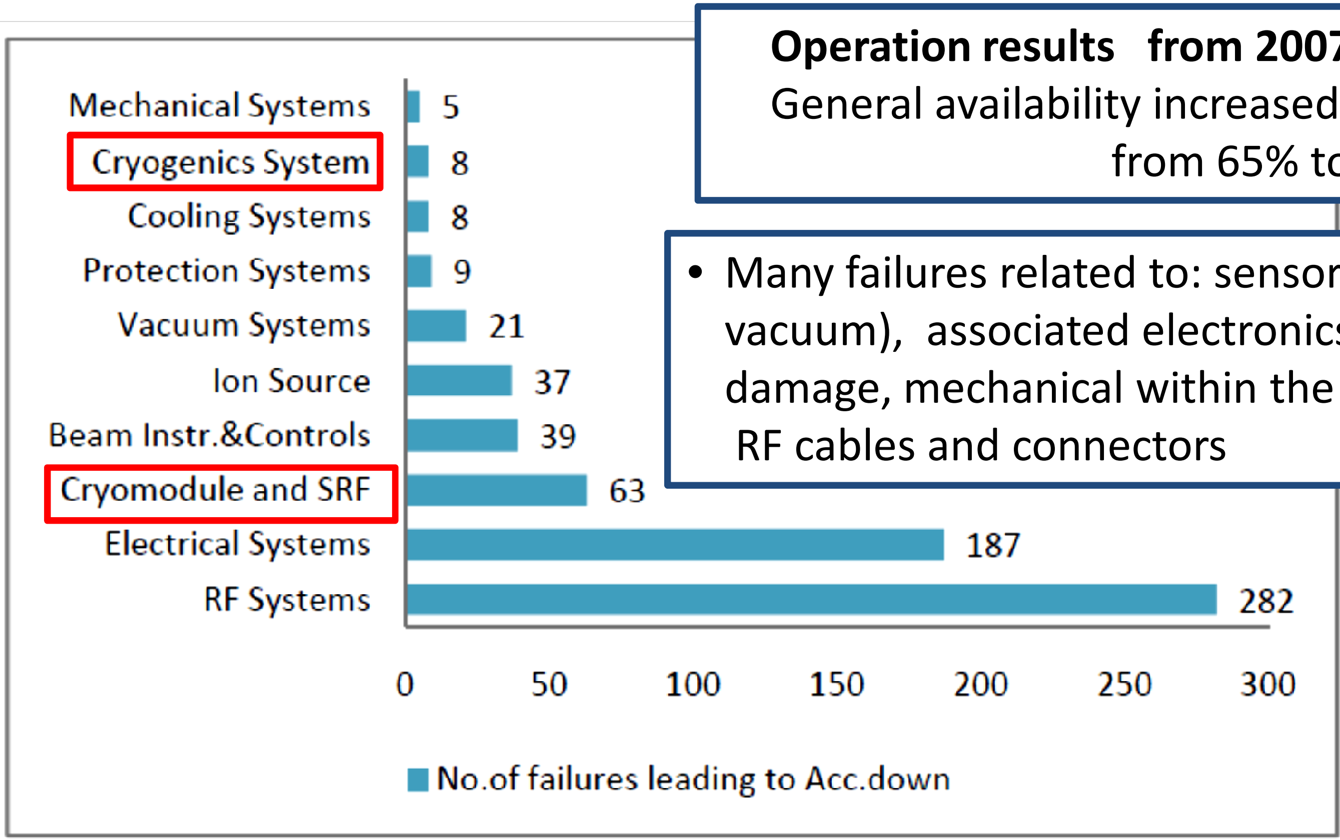
1. **HERA** – SC synchrotron operated at DESY Hamburg in the **period 1992 - 2007**

- **3 refrigerators of 6.4 KW @ 4.5 K each**
- **Cryogenic availability 99%**
- **Downtime related to cryogenics failures ~ 1000 hours**



- **process computer**: many short interruptions
- **power outages** : 2.5 per year
- **compressors failures:** 3 per year

2. SNS Cryogenic system reliability



Operation results from 2007 to 2011
General availability increased:
from 65% to 86%

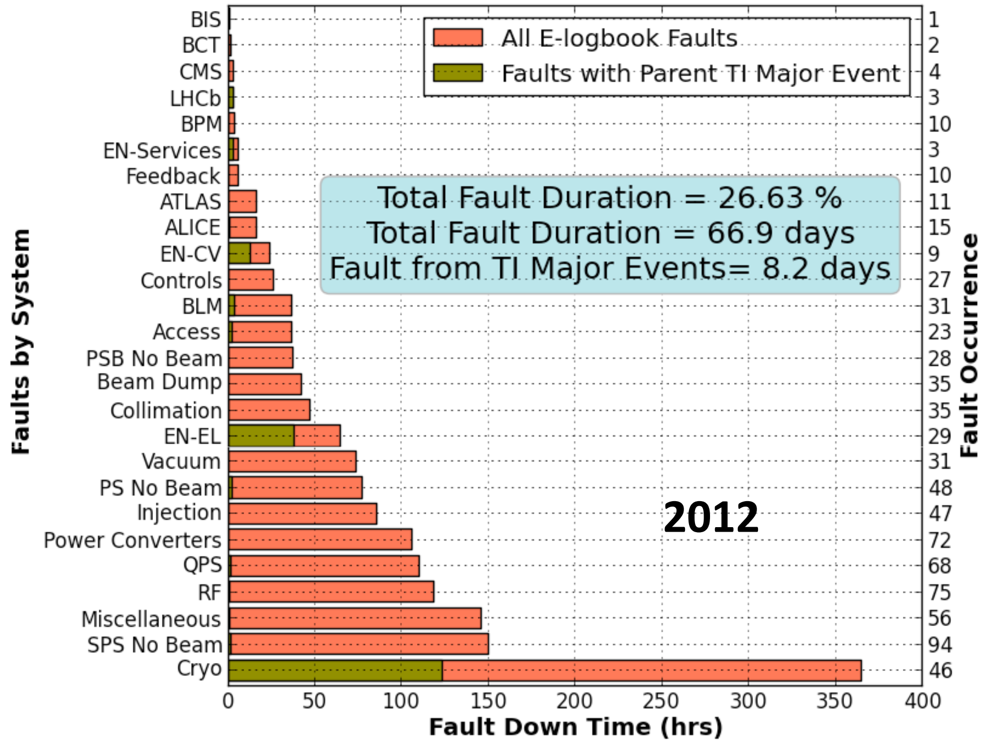
- Many failures related to: sensors (pressure and vacuum), associated electronics due to radiation damage, mechanical within the cryomodules, RF cables and connectors

Work in the MAX project: modelling of failures events in SNS, detailed analysis of events (cf. presentation of A. Pitigoi)

3. LHC cryogenic system reliability

- **2011** operation 269 days,
  → 63 days stable beams (23.4%)
- Downtime (failures) → 73 days
- Cryogenics systems → 48 days
  (both technical stops and failures)
  failures only (26 days)
- **Cryogenics availability: 90%.**

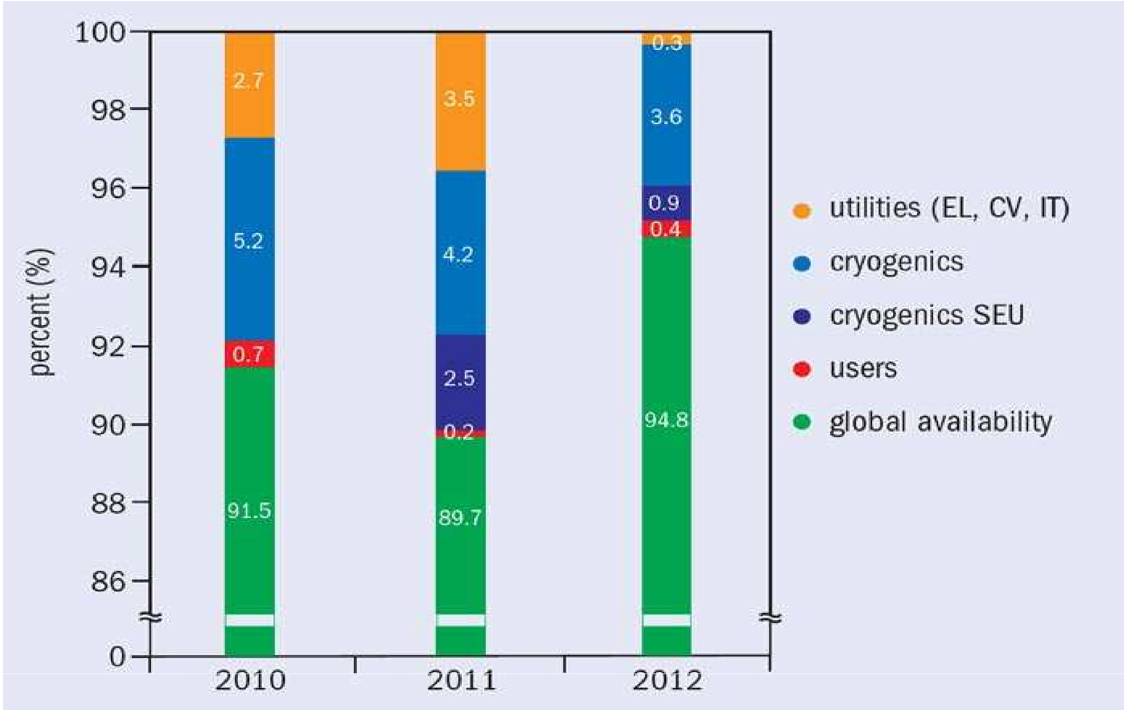
- **2012** operation 257 days
  → 73 days stable beams (28.4 %)
- Downtime (failures) → 67 days
- Cryogenics failures 15 days,
- **Cryogenics availability: 95 %.**



- On average, one refrigerator can be run for 8-9 weeks without interruption
- This figure is close to the 3 month irradiation periods foreseen for MYRRHA.

Availability of
LHC cryogenisc System
(CERN Courier Sept. 2013)

(SEU: single event upset
related to neutron radiation effects
on electronic cards)



The LHC operation is extensively analyzed, allowing detailed analysis of the cryogenic system reliability. Several major failures causes have been identified:

1) **Compressor station failures** are the most critical (vibrations, friction), as they completely forestall refrigerator operation.
2) **Turbine failures**, only reduces helium supply by a small percentage.
3) **Other component** faults cited are: oil pumps, compressors shaft seals, and control valves of turbine bearings.
4) **Impurity problems** are cited as one of the recurrent failure causes.
5) A more insidious cause of LHC cryogenic system shutdown have been **controller malfunctions due to neutron irradiation** coming from residual radioactivity induced by the beam losses.

More recent reliability results:

LHC last results : one refrigerator (equivalent of MYRRHA) operates 9 weeks without interruption (equiv. MTBF : 1500 hours)

More recent reliability evaluations :

Reliability Analysis for Project X (2012)

- **Cryoplant (based on SNS) : MTBF 1300 hours**
  Warm compressors 6500, 4.5K coldbox 5300,
  turbine expanders 30000, 2.1K coldbox 2500

- **Medium beta SC (1 module, 4 cavities): 4500 h**
  Failures contribution : Sensors 54 %
  Helium circuit 19 %
  Tuner 17 %
  Coupler 7 %
  RF cables : 1 %

Recommendations for the MYRRHA Cryogenic Plant

- **MAINTENANCE**: Mean Time Between Maintenance (MTBM) should be > 8000 hrs
  Oil checks, screw compressors controls every 10000-15000 hours, vibration surveillance program, etc.

- **CONTROLS**: special care of cryogenic control systems, radiation damages on sensors and electronics

- **IMPURITIES** : Valves, heat exchangers and turbines are particularly sensitive elements to impurities (dust, oil, gases). Improvements are necessary to keep a minimal level in these components.

- **Redundancies studies** for all elements containing moving/vibrating parts (turbines, compressors, including their respective bearings and seal shafts) are necessary.

- **Utilities** : Special control and maintenance of utilities equipments (supply of cooling water, compressed air and electrical supply).

- **Vacuum** : Periodic vacuum checks to identify leakage appearance: Insulation vacuum of transfer lines and distribution boxes.

- **Cold Compressors**: Easily exchangeable cold compressors.